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Wind power engineering in the world and perspectives of its development in Turkey

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Abstract

The development of a world wind power for the last decade is reviewed. Leading positions are taken by Germany, Spain and USA. The rates of growth of this branch of power engineering exceed 39% annually. It seems that the wind power is esteemed in these countries as the most perspective branch of electric power industry. The great success achieved by Germany and Spain in last years in developing wind power industry served as an example for all countries that have wind energy potentials. Information describing growth of powers, single wind power turbines, dynamics of increments of power of WPT on separate countries are submitted. During the last 10 years, the cost of WPT construction decreased more than twice, and it seems that specific investment costs reached a stable point for about 10 years. Furthermore, it can be concluded from wind farm investment costs that the cost of a WPT is about 1.3 times the cost of wind turbine. The information on the sizes of large WPT are adduced.

Keywords: Renewable energy; Wind energy; Wind turbines; Electricity production; Economy of wind power; Energy Policy; Wind farms; Turkey

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1. Introduction

Turkey is known to have dynamic economic development and rapid population growth. As Turkey's economy experienced high level of growth in the mid-1990s, the country's industrial production resulted in high level of pollution and greater risks to the country's environment. Turkish energy consumption has risen dramatically over the past 20 years. From just 24 Mtoe in 1980, Turkey's domestic energy consumption has nearly increased three times, reaching a level of 77.1 Mtoe in 2000 [1]. This level is still low relative to similar-sized countries such as Germany (337.2 Mtoe), France (255 Mtoe), UK (230.32 Mtoe) and Ukraine (148.39 Mtoe). In 2000, the total carbon emissions were 204.08 Mtoe and have risen in line with the country's energy consumption in Turkey. Since 1980, Turkey's energy-related carbon emissions have jumped from 18 Mtoe annually to 47.1 Mtoe in 1998 [2]. Almost 26% of carbon emissions in the country is contributed by the power-engineering sector.

According to last data [3], the installed capacity of electric power plants (EPP) in Turkey in 2000 was 26,457 MW and electricity consumption—104.52 TWh or 1564 kWh per capita. For comparison, the value for Germany is 6684, Greece—4694, Ukraine—2755, Russia—5236, and Iran—1596 kWh/capita [1]. During next 20 years, the EPP's installed capacity is planned to reach 109,227 MW and annual electricity production by 623.835 TWh. The share of thermal power plants in production will be 71.96%. It is more than the average share of 65.25% for 1995–2000. During the same period, hydro power plants produced, in average, 34.75% of electricity [4]. In 2020, in total production of electricity, the share of renewables (including hydropower) to be planned only 16.69% or 104.11 TWh. In the process of electricity production, the emission of pollutants in air from German sources [5] are presented in Table 1. It is seen that the main sources of carbon emissions are thermal power plants. Consequently, in the next 20 years, emissions from thermal power stations is expected to increase.

The world community is known to stand in front of the global ecological problem—greenhouse effect. During the last years we observed a gradual growth of carbon content in

Table 1
Emissions for generation of electricity in Germany [5]

Energy carrier	Share, 1995 (%)	Radioactive waste (mg/kWh)	SO_2 (g/kWh)	NO_x (g/kWh)	Dust (g/kWh)	CO_2 (g/kWh)
Nuclear energy	29.1	4.0	0.13	0.14	0.03	35
Brown coal	27.6	–	0.43	0.79	0.10	1133
Hard coal	27.4	–	0.79	0.78	0.11	917
Natural gas	7.0	–	0.01	0.66	0.01	402
Hydropower	4.6	–	0.00	0.00	0.00	1
Wind energy	0.5	–	0.02	0.05	0.02	18

air. Taking the alarming tendency into account, many countries signed, in 1998, the United Nations Framework convention of Climate Change (Kyoto Protocol, 1998), according to which they have assured to cut carbon emissions by 2008–2012. Some countries including Turkey did not sign the Kyoto protocol. Nevertheless, in planning the strategy of its power-engineering development, the importance of strong environmental protection measures, the fragility of Turkey's nature, the requirements and recommendations of EC and IEA, as well as the fact that Turkey is one of the European centers of tourism should be taken into account. In the light of above-mentioned, Turkey stands before a serious problem of choice between directions of development in power engineering.

The last decade was characterized by rough development of wind power engineering all over the world. The average annual increment in installed wind turbines capacity as will be shown below made more than 39%. No other branch of power engineering did not develop with such high rates. During the last years, excellent reviews devoted to wind energy technology were published [6–8]. These reviews consider practically all aspects of wind technology development. The development of wind power engineering in separate years along with countries and regions as well as production of wind turbines can be found in [9–21]. At the same time, it indicates the increased interest of Turkish researchers to study wind energy potentials in Turkey [22–43]. Majority of publications consider, as rule, potentials in separate regions. These assessments of wind potential in Turkey are based on data registered at weather stations of the State Meteorology Organization. Last investigations show that these data do not reflect the true situation relating to wind energy potentials.

Below, we shall consider the quantitative and qualitative development of wind power engineering in the world, the potentials of wind energy technology in general balance of electricity production, the main manufacturers of wind turbines, the largest wind farms, the investment costs and other major indices in development of the given branch of power engineering. Other aims of this paper are to summarize the results of Turkish investigators for developing the recommendations on overcoming the barriers that hamper of wind energy technology progress in Turkey. One may expect wind power engineering to be considered as one of the possible directions of power engineering development in Turkey in 21st century.

2. The state of wind power engineering

The geography of distribution of wind power turbines (WPT) for countries and regions is shown in Table 2. Only the countries, where the installed power WPT is equal to or exceeds 1 MW, are listed in this table. European countries and USA take the leading positions. It is not surprising because these countries are given attention to development of wind power since the 1980s. However, it should be noted that developing countries have also been mentioned in this table. The success of India and China should be pointed out. The interest of developing countries to develop the wind power is conditioned, first of all, by lack of own fuel and energy resources. Here indepen, Iran standing out separately, has huge reserves of oil. And the interest of Iran to wind power is evidently called by ecological reasons. The majority of countries listed in Table 2 are the seaside countries with high winds for near-shore areas. Nevertheless, this table mentions inland countries like Austria, Czech Republic and Switzerland.

The data presented in Table 2 indicate the general conditions of development of wind power in separate countries. However, they do not reflect the dynamics in development of this branch during the last years. Table 3 [9–21] demonstrates the increment in power capacity of the WPT in countries where the general installed capacity exceeds 100 MW on December 31 2002. The capacity of WPT installed all over the world within 5 years, as it is seen from Table 3, has grown 5.29 times, which corresponds to an annual growth of

Table 2
Installed wind power capacity in the world

No	Country	MW	No	Country	MW
1	Germany	11968	24	Costa Rica	71
2	Spain	5043	25	Belgium	45
3	USA	4674	26	Ukraine	44
4	Denmark	2880	26	Finland	39
5	India	1702	27	Latvia	24
6	Italy	806	28	Brazil	19
7	The Netherlands	727	29	Turkey	15
8	United Kingdom	570	30	Luxemburg	14
9	Japan	486	31	Argentina	12
10	China	473	32	Czech Republic	11
11	Greece	462	33	Iran	11
12	Sweden	372	34	Tunis	8
13	Canada	270	35	Israel	8
14	Portugal	204	36	Russia	7
15	France	183	37	South Korea	6
16	Ireland	167	38	Switzerland	5
17	Australia	143	39	Mexico	5
18	Austria	130	40	New Caledonia	7
19	Egypt	125	41	Sri Lanka	2
20	Norway	97	42	Jordan	1
21	New Zeeland	82	43	Romania	1
22	Morocco	54	44	Rest countries	12
23	Poland	54	45	Sum	32039

Status to end of 2002 [14,21,45].

39.54%. The highest rates of growth (more than 15 times) have been achieved in countries like Egypt, Greece, Japan, and Austria, where the reference level of development of wind power engineering was rather low. Canada, Spain and Italy follow these countries (7–10 times). The highest increment in installed powers is seen in Germany, Spain and Italy, wherein the targeted policy is conducted. In the remaining countries, the increment was irregular, which is characteristic of the uncontrolled market. Especially, it is seen on an example of USA. Nevertheless, the definite measures adopted by the Congress of USA on stimulation of development of wind power industry, have resulted in essential increase of generating powers in 2001. The lowest increment was observed in India, Great Britain, Sweden, Denmark, and USA where the wind power industry had enough high levels. The actual increment in installed capacity of WPT in the world during the years 1998–2002 years authority confirmed the prognosis that was made in 1998 by the world, the BTM Consult ApS Company. For Spain, USA, Denmark, Italy, assessments (with inaccuracy ±13%) were close to real indices. The predictions relating to Great Britain, China, Sweden, Canada and Ireland as well as CIS countries were too optimistic. The estimations concerning Germany have appeared pessimistic.

The rapid development of wind power in maiden group of countries, in our view, is conditioned by that fact that the governments, the power companies, and population of these countries have realized, that the development of wind power engineering has left the pioneering period of development, both at a technological level and economic indices. The large power companies of the maiden group of countries, as a rule, became holders of the maiden large constructed WPT. It speaks that the wind power is esteemed in these countries as the most perspective branch of electric power industry. The second group of countries still is on the crossroads and consequently higher rates of these countries still at the front. At the same time, rates of growth in maiden group of countries in the process of further development, apparently, will be reduced step-by-step. It is regarding Germany where the regions with high wind speed are limited. At the present time, the installed wind turbine capacity in Germany exceeded the technical potential level by 12,000 MW estimated in [46]. Nevertheless, the great success achieved by Germany and Spain during the last years in developing wind power industry has served as an example for all countries that have wind energy potentials.

Above we have considered the absolute indices of leading countries in the world for the last years. The more visual representation on development of wind power engineering along separate countries can be obtained from Table 4 [1,14,21]. Denmark, as shown in Table 4, has considerably anticipated remaining countries on specific indices. It should be noted that the indices of separate northern federal states in Germany come nearer to indexes of Denmark, while the southern states, where wind resources are much lesser, lag from maiden. The power density of WPT, reached in Denmark, can be utilized as a reference point for the calculation of wind power resources with similar conditions in this or that country. It is possible that the number of countries indicated in Table 4 can be filled up such countries as Morocco, Egypt both other seaside countries and island states, which disposes considerable wind resources.

Electricity produced by WPT grows from year to year and its share in some countries already makes a considerable share of electricity consumed in the country. Table 5 [47–49] shows an increase in electricity production by WPT in countries like Denmark,

Table 3
Wind power increments in some countries [9–21]

No.	Country	Installed capacity to end of 1997	New installed capacity, MW					Installed capacity to end of 2002	Prognosis capacity until 2003 [17]	Defacto/ prognosis, %	Average annual incre-ment,%
			1998	1999	2000	2001	2002				
1	Germany	2081	793	1556	1665	2659	3247	11968	6774	177	41.9
3	Spain	512	368	932	1024	835	1493	5043	5580	90	58.0
2	USA	1511	577	324	30	1695	429	4674	4141	113	25.3
4	Denmark	1116	310	328	603	135	593	2880	2645	109	20.9
5	India	940	82	43	169	250	195	1702	1942	88	12.6
6	Italy	103	75	80	147	245	106	806	872	92	50.9
7	The Netherlands	392	50	54	40	42	219	727	1179	62	13.1
8	United Kingdom	328	10	24	63	66	55	570	1313	43	11.7
9	China	146	54	25	84	90	67	473	1100	43	26.5
10	Greece	29	26	103	116	0	104	462			66.6
11	Sweden	122	54	44	45	49	55	372	896	42	25.0
12	Japan	31	22	28	57	150	129	486			73.4
13	Canada	25	57	42	12	70	56	270	533	51	60.9
14	Portugal	39	13	10	50	15	51	204			39.2
15	Ireland	53	11	10	49	2	13	167	344	49	25.8
16	Austria	10	15	9	35	17	44	130			67.0
17	Rest countries		96	279	308	464					
18	Sum	6056	2598	3924	4495	6824	7231	32039	31833	101	
19	Annual increment, %		42.90	45.34	32.26	36.99	29.15	Average annual increment in 1998–2002 (39.54%)			

Table 4
Wind turbines specific installed capacity (status to 31 December 2002 [1,14,21])

No.	Country	Accumulated installed capacity, (MW)	Population, 2000 (Million)	Territory (km^2)	Specific installed capacity	
					W/capita	kW/km^2
1	Denmark	2880	5.34	43094	539	66.83
2	Germany	11968	82.17	357022	146	33.52
3	Spain	5043	39.93	504782	126	9.99
6	The Netherlands	727	15.92	41526	46	17.51
5	Ireland	167	3.79	70273	44	2.34
8	Greece	462	10.56	131957	44	3.50
7	Sweden	372	8.87	449964	42	0.83
4	Luxemburg	15?	0.44	2586	34	5.8
11	Portugal	204	10.01	92345	20	2.2
9	Costa Rica	71	3.81	51060	19	1.4
10	USA	4674	275.42	9809155	17	0.48

Germany, Spain Ireland, and the Netherlands. Two percent level in Denmark, as seen from the table, was overcome in 1990. It is expected that Spain overcame 3% level in 2003, Germany has reached 2% level only in 2002, and Ireland overcame 1% level in 2000 after 5 years of development. Netherlands's can reach 1% level in 2002. Great Britain [50], producing WPT of 1.24 TWh electric energy has satisfied its needs (0.37%). Thus, the example of Denmark demonstrates that countries having considerable wind resources can satisfy their electricity consumption by 10% and greater. Ten years ago, a little was expected, that WPT can compete with other types of power generation plants.

Table 5
The share of wind electricity produced in some countries [47,48]

Year	Germany		Denmark		Spain		Ireland		Greece	
	TWh	%*	TWh	%	TWh	%	TWh	%	TWh	%
1990	0.043	0.01	0.610	2.1	0.014	0.01	0	0	0.002	0
1991	0.160	0.03	0.740	2.5	0.015	0.01				
1992	0.276	0.05	0.915	3.0	0.031	0.03				
1993	0.593	0.11	1.034	3.4	0.111	0.07				
1994	0.909	0.17	1.137	3.6	0.175	0.11				
1995	1.712	0.32	1.174	3.7	0.270	0.16	0.016	0.09	0.034	0.08
1996	1.994	0.37	1.227	3.8	0.364	0.21	0.014	0.07	0.038	0.09
1997	3.040	0.55	1.932	6.0	0.742	0.39	0.050	0.25	0.036	0.08
1998	4.593	0.82	2.820	8.2	1.352	0.69	0.169	0.81	0.070	0.15
1999	5.528	1.00	3.029	7.8	2.744	1.31	0.187	0.86	0.162	0.33
2000	9.352	1.64	4.242	11.8	4.955	2.20	0.244	1.03	0.451	0.84
2001	10.700	1.84	4.299	11.4	6.969	2.97	0.334	1.36	0.756	1.42
2002	16.500	2.84	4.877	12.6			0.389	1.60	0.834	1.66

*The share of electricity produced by WPT from total electricity generation.

Table 6
WT utilization capacity factor for some countries and wind farms [9–21,49], %

Country/wind farm	Vav*	1996	1997	1998	1999	2000	2001	2002	η_{av}
Ireland (IR)			17.3	33.0	30.9	28.3	30.4	30.0	28.3
Spain (SP)		23.3	24.0	27.6	23.3	24.3	17.0	18.5	22.6
Denmark (DK)		19.0	22.6	25.8	21.9	23.7	20.5	21.3	21.6
Germany (DE)		17.0	19.1	21.8	18.3	19.7	18.4	18.2	18.9
Greece (GR)			14.7	19.5	17.5	23.9	14.0	21.0	18.4
The Netherlands (NL)			17.3	20.0	17.7	20.3	21.6	16.3	18.9
Cronolacht (IR)				45.7	46.5	43.1			45.1
Tunø Knob Off-shore (DK)	7.6	30.2	31.3	36.2	32.7	36.2			33.3
Hiddum Houw Wind Farm (DK)	7.3	27.8	28.0	34.1	17.3	35.3			28.5
Klim Wind Farm (DK)	6.7			27.1	24.0	26.8			26.0
Gipsøn Vind (DK)	7.1			27.6	24.0	25.0			25.5
Burgenwindpark (G)	6.9			22.6	20.7	22.5			21.9
Fjaldene Wind Farm (NL)	6.1	20.7	20.1	22.8	24.1	21.2			21.8

*Average yearly wind speed in this location. measured during several years.

According to [51] in present time, the average capacity factor of WPT lies within 23–25%. In this point of view, it is interesting to compare the data (see Table 6) for the six countries reviewed above, as a whole and for some projects [52], which were realized by Vestas Company. The mean annual power was an average value of an installed power at the end of the previous year and current year, and operating ratio of power calculated by the formula:

$$\eta = \mathrm{E}/(\mathrm{N}P_{av}),$$

where E, electric energy produced actually by WPT; N, Number of hours in 1 year; $P_{\rm av}$-mean annual installed capacity.

Table 6 indicates that the mean capacity factor calculated for The Netherlands and Greece, are very close and have the lowest value among the considered countries. Denmark and Germany take a little bit more than The Netherlands and Greece. Wind resources in Spain are, on an average 25% than that those of Denmark and Germany, and the capacity factor for Spain agrees with those values mentioned above [48], while the data for Ireland lay higher than all of other countries. It means that the wind resources in Ireland are sufficient and evidently the highest in Europe. When comparing indices for separate wind farms (power of WPT varies from 3 up to 21 MW), it becomes apparent that, with the growth of wind speed capacity factor, the WPT also grows. An example of a farm constructed at Cronolacht (Ireland) demonstrates that, as far as can increase capacity factor under favorable conditions. Since practically all modern WPT are designed for

Table 7
Largest projects of utilization of wind energy for electricity production [53–64]

No	Project	Country	Commissioned year	Number installed turbines	Wind turbine manufacturer	Wind turbine type	Installed capacity (MW)
1	California's Tehachapi Pass	USA	1985	>5000	Various	Various	620
2	California's Altamont Pass	USA	1985	>6000	Various	Various	548
3	California's San Gorgonio Pass	USA	1985	>3500	Various	Various	421
4	Texas's King Mountain	USA	2001	214	Bonus	B-1300	278.2
5	New Mexico's Wind Energy Center	USA	2003	136	GE Wind Energy	GE-1.5	204
6	Iowa's Storm Lake (I+II)	USA	1999	259	Enron	Zond-750	194.25
7	Washington's Stateline Wind Project	USA	2001	273	Vestas	V47-660	180.2
8	Texas's Indian Mesa (I+II)	USA	2001	107	Enron	1.5 s	160.5
9	Horns Rev Wind Farm	Denmark	2002	80	Vestas	V80-2.0	160
10	Texas's Woodward Mt	USA	2001	242	Vestas	V47-660	159.46
11	Nysted Offshore Wind Farm	Denmark	2003	72	Bonus	Bonus-2.2	158.4
12	Texas's Trent Mesa	USA	2001	100	Enron	1.5 s	150
13	Albacete's Higueruela (I+II)	Spain	1999	169	Vestas	V47-660	111.52
14	Minnesota's Lake Benton-1	USA	1998	143	Enron	Zond-750	107.25
15	Texas's Southwest Mesa	USA	1999	107	NEG Micon	NM-1000	107
16	Minnesota's Lake Benton-2	USA	1999	138	Enron	Zond-750	103.5
17	Iowa's Handcook County	USA	2002	148	Vestas	V47-660	97.68
18	Aragon's Tardienta (I +II)	Spain	2001	127	Gamesa	G-47; G-52	93.7
19	Oregon's Umatilla	USA	2001	127	Vestas	V-47-660	84
20	Texas's Pecos County	USA	2001	125	Vestas	V47-660	82.5
21	Iowa's Worth County	USA	2001	89	NEG Micon	NM-900	80.1
22	Texas's LianoEstacado	USA	2001	80	Mitsibishi	M-1000	80
23	California's Mountain View (I+II)	USA	2001	111	Mitsubishi	MWT-600	66.6
24	California's Solano County	USA	1985	613	US Windpower	Various	64
25	California's Whitewater Hill	USA	2002	41	GE Wind Energy	GE-1.5	61.5

(continued on next page)

Table 7 (*continued*)

No	Project	Country	Commis-sioned year	Number installed turbines	Wind tur-bine man-ufacturer	Wind turbine type	Installed capacity (MW)
26	Wyoming's Foot Creek Rim I	USA	2000	90	Mitsu-bishi	MWT-1000	60
27	Navarra's Montes de Clerso	Spain	1999	n/a	Ecotecnia	n/a	59.5
28	California's Cameron Ridge	USA	1999	80	NEG-Micon	NM-700	56.0
29	Campania's Molinary Ridge	Italy	1999	90	Vestas	V42; V44	54
30	Koudia-al-Blanco	Morocco	2000	84	Vestas	V42-600	50.4
31	Albacete	Spain	2001	67	Enron	750i	50.25
32	Wyoming's Rock River I	USA	2001	50	Mitsu-bishi	MWT-1000	50
33	Aragon's La Seretta	Spain	2000	75	Gamesa	G-47-660	49.5
34	Castilla's La Mancha's Lianos	Spain	1999	75	Gamesa	G-47-660	49.5
35	Castilla's Molar del Molinar	Spain	2001	75	Gamesa	G-47-660	49.5
36	Galicia's Mas Galan	Spain	2001	75	Gamesa	G-47-660	49.5
37	Galicia's Monto Redondo	Spain	2001	n/a	Ecotecnia	n/a	49.5
38	La Rioja's Cabimonteros	Spain	2001	75	Gamesa	G-47-660	49.5
39	Asturias's La Bobia-San Isidro	Spain	2001	58	Gamesa	G52-850	49.3
40	Castilla-LaMancha's Campalbo	Spain	2002	58	Gamesa	G52-850	49.3
41	Castilla-Leon's Carrasquillo	Spain	2002	58	Gamesa	G52-850	49.3
42	Caixado y Peca da Loba	Spain	2002	74	Made	AE-46	48.84
43	Castilla's La Mancha's Virgen	Spain	2000	74	Gamesa	G-47-660	48.84
44	Galicia's Muras (I + II)	Spain	2000	74	Gamesa	G-47-660	48.84
45	Navarra's Penablanca	Spain	2001	74	Gamesa	G-47-660	48.84
46	A Coruja's Somozas	Spain	1999	n/a	Ecotecnia	n/a	48
47	Castilla's Malefaton	Spain	2000	71	Gamesa	G52-850	46.86
48	California's Pacific Crest	USA	1999	69	Vestas	G47-660	45.54
49	Middelgrunden Offshore Plant	Denmark	2000	20	Bonus	Bonus-2MW	40

a nominal wind velocity of 12–16 m/s, as the wind speed is approaches the nominal one, the capacity factor also increases. For comparison, the capacity factor calculated from the data of Ref. [49] for three wind farms operated in Turkey at present gives a value of 19.8%, which is very close to values obtained for Greece and The Netherlands.

The oil crisis during 1973–1974 is known to have stimulated the developments in the field of renewable sources of energy. Three giant projects were realized as a result of these activities in 1981–1985 in California, USA (see Table 7). California's projects [53] served

long time, mainly, as demonstration projects. Danish companies manufactured the majority of WPT constructed in California. These projects have served as potent stimulants for their further development. Apart from California's projects, Table 7 [53–64] also presents the largest projects, the installed capacity of which equals or exceeds 40 MW. It is not difficult to note that all these projects were realized during the 4 years mainly in USA and Spain. The large wind farms are the property of large power delivery companies including General Electric Wind Energy (USA) and Gamesa (Spain). Large companies are able to concentrate on the great financial and technical resources to construct, in short time, the large wind farms. The fast growth of constructed WPT in noted countries is caused, besides the above-mentioned factor, by rich wind resources, the not processed grounds, and the favorable laws of federal and local authorities. The high density of population, dense grid of industrial enterprises and communication lines, absence of large massifs of free lands hinders is hindered with the realization of the large projects in countries like Denmark, Germany and The Netherlands. Nevertheless, these countries have considerable near-shore areas, where the depth of water does not exceed 10 m. This circumstance provides to these countries considerable wind resources. The last circumstance was utilized by Denmark in Middelgrunden Offshore Plant (2000, 40 MW), Horns Rev Wind Farm (2002, 160 MW), and Nysted Offshore Wind Farm (2003, 158.4 MW) in Northern Sea near of Denmark beaches [61–64]. These projects, undoubtedly, are the largest projects that were constructed in offshore zone. In the nearest future, Denmark plans to install in offshore regions wind power capacity of 750 MW. Great Britain, as well as other countries, considered similar projects.

3. Wind turbine production

The last years were characterized by constant increase in power of the developed WPT and decrease in their specific cost. Therefore, if WPT installed in California had power, on an average of about 110 kW, the turbines, which were mounted in the beginning of the 1990s already had, in an average about 200 kW (see Fig. 1). The data borrowed from [6,45,65–67] and presented in this figure illustrate dynamics of the growth of power of WPT in different countries. Towards the end of twentieth century, the mean installed power of WPT was about 1 MW, and in Germany the index was higher. In 2002, the average installed power reached 1395 kW per a wind turbine [66] in Germany. It is explained by necessity to use the limited wind resources in maximal level. At the same time, the average size of new by installed turbines [45] was 1060 in Canada, 1337 Denmark, 2000 Finland, 1603 The Netherlands, 2200 Norway, and 1020 United Kingdom. In other IEA countries, this value varies between 774 and 950 MW. It is obvious that first group of IEA countries try to use having the area in maximal degree. In Spain, where there are many territories with high wind speed and low density of population, the average power capacity of wind turbines installed in 2002 reached only 808 MW. The tendency of growth in capacity of separate wind turbines will be remaining up to the moment when the capacity reaches the optimal value. A further increase could lead to investment growth in fundamental and hub expenses. At present, some companies already produce WPT with 2

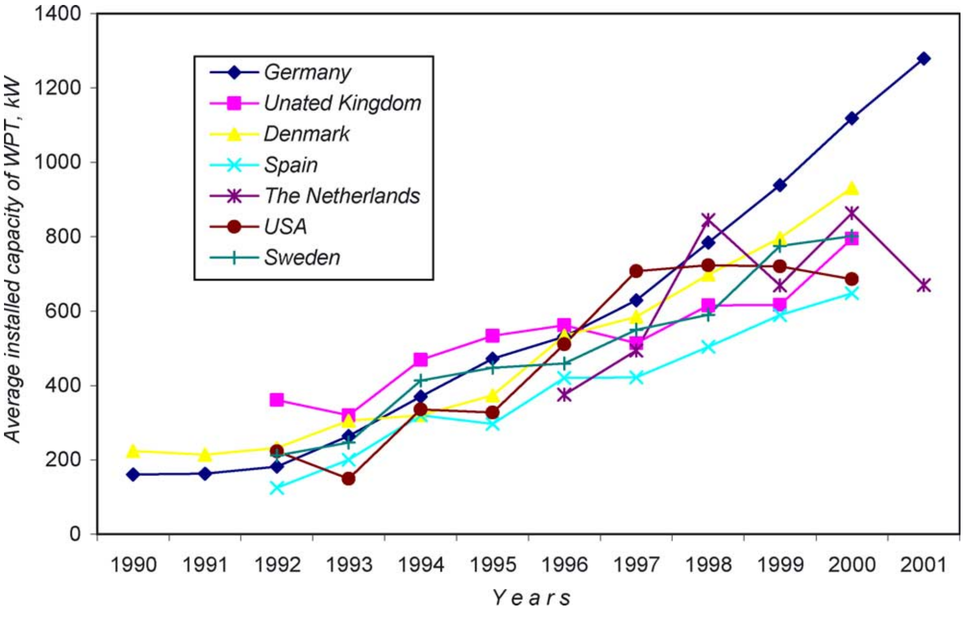

Fig. 1. The change of the average installed capacity of WPT [7,65–67].

and 2.5 MW [55,60,68,69]. WPT with 3.5 and 5 MW will be manufactured in the next 3 years [7,70–72].

All leading manufacturers of turbines are submitted in Table 7. A brief information on 12 companies manufacturing more than 98% world productions of WPT is presented in Table 8 [14,21,58,60,68,73–78]. The majority of companies indicated in this table, under the essence international, has the plants and divisions in many countries. The precipitant development of wind power engineering has demanded from manufacturers the adequate growth of manufacturing powers. Therefore, merging of companies, absorption of one company by other (as in a case with GE Wind Energy) etc, are not surprising. Such power giants as General Electric (USA), Babkock and Borsig AG (Germany) have already paid attention towards this branch of power engineering. Apparently, this process will be prolonged, since doubling and trebling of the share of the wind power engineering in general balance of power engineering in the nearest years is expected.

It is easy to note that the Danish manufacturers of wind turbines are leaders among 11 world top manufacturers presented in Table 8. They produce more than 50% of the world total production of wind turbines. The German companies as well as other wind turbines manufacturers are behind them. It should be pointed out that the successes of Enercon and Gamesa promoted sufficient contribution in the development of wind power industry in Germany and Spain, respectively. The capacity of WPT manufactured in last years increased very rapid. The number of the top sold and installed types of wind turbines is given in Table 9. Among the presented classes of wind turbines, the most widely distributed ones are noted by bold type. The brief performances of these wind turbines can be found in [7]. The great successes as it is seen from Table 9 had such model as the E-40

Table 8
The main manufacturers of large wind turbines [55,59,62–69]

No.	WT Manufacturer	Country of foundation	Year of first installation	Installed capacity of WPT, MW		
				To end of 1995	Only in 2002	Accumulated to end of 2002
1	Vestas Wind Systems	Denmark	1980	273	1561	≈7000
2	NEG Micon[a]	Denmark	1983	183	867	5010
3	Enercon AG	Germany	1985	163	1272	3189
4	GE Wind Energy[b]	USA/Germany	1981	260	860	4461
5	Bonus[c]	Denmark	1980	88	587	2769
6	Gamesa Eolica[d]	Spain	1994	19	854	2815
7	Nordex AG[e]	Denmark	1987	55	457	1862
8	Made Energias*	Spain	1996	n/a	191	790
9	REpower Systems	Germany	1987	2	227	680
10	Ecotecnia	Spain	1992	4	120	456
11	DeWind AG*	Germany	1996	0	>87	>300

*Authors' estimations.
[a] Nordtank Energy Group A/S and Micon A/S merged into the new company NEG Micon A/S on July 1997.
[b] General Electric Co. bought in 2002 Enron Wind that has been founded in 1997 on the basis of Zond System Inc., Kenetech (USA). and Tacke Windtechnik GmbH Germany).
[c] Including WPT produced by AN Windenergie GmbH (Germany).
[d] The company founded as a Spanish joint venture by Gamesa Group (51%). Danish Vestas A/S (40%) and the branch of local Spain province government Sodena (9%). In 2001 Gamesa Group has bought the share of Vestas.
[e] German company Balke Dürr GmbH has bought in 1996 ГоДу 51% actions of Nordex; Presented data include WPT produced by SüdWind Energy GmbH.

(Enercon), Bonus-600, Vestas V-47, Zond-750 (Enron), Bonus-1000, Bonus-1300, Enercon-E66, Vestas V-66, Bonus-2000, and Nordex-2500. The model V-47-660 developed by Vestas and manufactured by Vestas and Gamesa leaves behind other models on sold units.

Speaking about a share occupied by this or that company in global market, it is possible to say, that if oscillated per miscellaneous years for last 6 or 7 years. It was also determined

Table 9
The most widely distributed types of wind turbines. Status to end of 2001 [55,59,62–69]

Type of WT (kW)	Bonus	Enercon	Enron	Nordex	Vestas and Gamesa
500		1950			495
600	1100	980	586	435	711
660					4298
750			791		
1000	341			174	
1300	584			442	
1500		378	821	100	
1650					259
1800		462			
2000	66				7
2500				13	

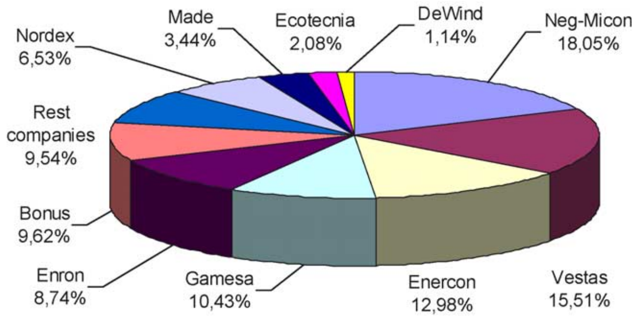

Fig. 2. The share of WPT manufacturers in the world market for period of 1996–2000 [8–21].

by precipitant development of the market of WPT and internal problems of companies, bound with dilating of effecting and simultaneous developing the new more perspective aggregates. Therefore, apparently, it is more correct to estimate for the five-year period. Fig. 2 illustrates distribution of the world market of WPT for a period from 1996 to 2000. From the manner the picture varies from year to year, it is possible to receive submission on an example of the company, Vestas. Therefore, in 2000 she has made and has installed WPT by power 804 MW, in 2001 already, 1630 MW.

The share of different countries in the world market of WPT, generalized for the period from 1998 to 2002 as shown in Fig. 3. The main markets are: Germany (37%), Spain (17%), USA (about 13%), and Denmark (9%). It is of no doubt that these countries in the visible future will stay as the main markets. Apparently the share of Germany and Spain will be reduced step-by-step, while the share of USA will increase at the expense of extension of measures of state stimulation in 2002 and 2003. Severe efforts are undertaken in Italy, Greece, Great Britain, Japan and Australia for development of wind power engineering. Therefore, in the next 5 years in these countries, the essential growth of generating powers is expected. In many respects, it is stipulated, in our opinion, by high prices paid to wind generators in these countries: Italy—11.83 US cents/kWh, Greece—6.4–7.4, United Kingdom—10.7, Japan—8.4 [45]. Brazil has accepted unprecedented measures for stimulation of wind power. According to this program [79], in 2002–2003, the government of Brazil will grant the tax abatements for the companies, which for this

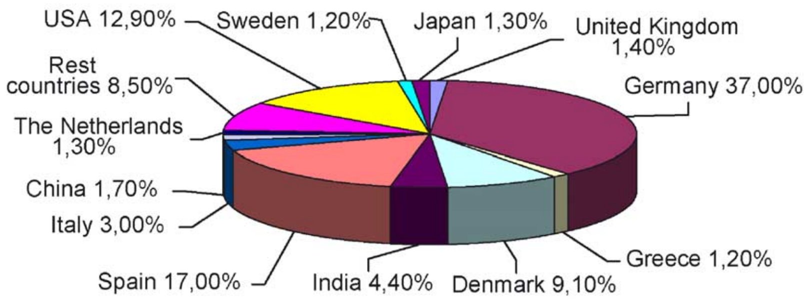

Fig. 3. The share of different countries in the world WPT market for period of 1996–2001 [8–21].

period will install WPT by power up to 1050 MW. Therefore, in accordance with [80], powers of WPT all over the world in the next 5 years will reach 60,000 MW. France plans to install 10,000 MW by 2010, Great Britain schedules furthermore to meet up on 10% the needs for the electric power at the expense of an WPT, India plans in the next 10 years to put into operation 6000 MW of powers, and Germany is going to construct the WPT with total capacity of 25,000 MW by 2010. The target of Spain is to reach 13,000 MW by 2011 [78]. According to the signed contract, during 2002 and 2003, Vestas [66] supplied 123 WPT to Iran with 660 kW capacity of each that will allow Iran to enter into 20 of the most advanced countries in the world. The achievements of Egypt, Morocco and Costa Rica serve an obvious case and for other developing countries, where there are considerable resources of wind energy. And consequently, the share of remaining countries also grow step-by-step.

4. The investment costs

The main problem determining the prospects of development of wind power engineering is the specific cost of capital investments. The change in the specific cost of WPT construction can be observed in Fig. 4. During last 10 years, this value decreased more than twice. As it is seen from this figure, during the last years the specific indexes were almost stabilized and reduced rather slowly.

Nevertheless, these values in many cases below, are comparable to indexes of thermal power stations working on coal [8] for which one specific investment estimated 1185–1295 ECU/kW (in the prices of 1992). The continuous increase in unit power of the WPT, on one hand, and far from optimum production volumes of this or that model of a WPT on the other hand seems to be the main reason for slowdown of paces in decreasing

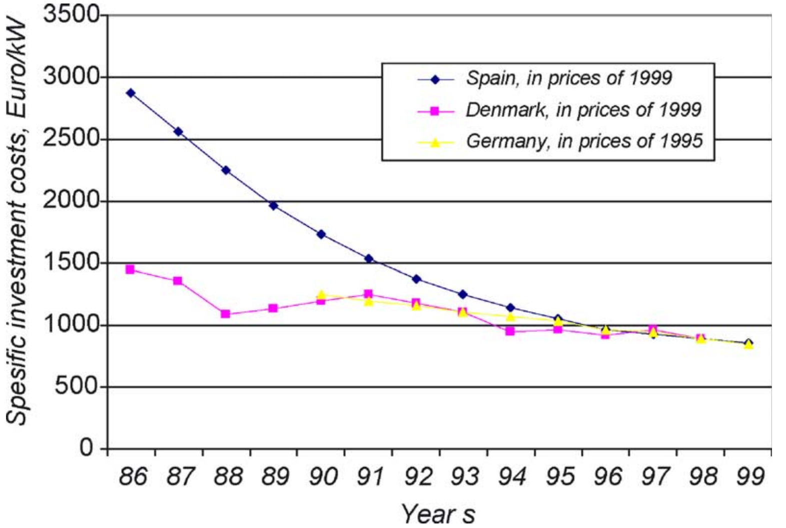

Fig. 4. Evolution of investment costs by countries [81].

the specific capital investments last years. At present, WPT with unit power of 2 and 2.5 MW [54,59,62,63] are manufactured. In the next 3 years, the main manufacturers of wind turbines are going to start the serial production of WPT with unit power of 3.5–6 MW [7,70–72]. The further sufficient decrease in specific investment costs is necessary to expect, not earlier, than in 10–12 years.

At present, we have information [45] on typical wind system cost obtained for some IEA countries. That value varies from 924 USD/kW in Denmark to 1196 in Norway. At the same time, the price paid to wind electricity generators changes from 2.9 (Sweden) to 11.83 US cents/kWh (Italy). From this, it can be seen that Denmark has the lowest investment cost for installed wind power unit. The low transportation and grid connection expanses promoted this. High specific investment cost in Norway is apparently stimulated by installation of newly developed wind turbines with high capacity (2–2.5 MW). Typical investment cost for wind farms constructed in Turkey is estimated as in 1181 Çeşme Alaçatı R.S. and 1275 USD/kW for Bozcaada R.S. Such high investment cost is probably caused by high interest rate, high transportation and electrical grid expenses.

In Table 10, information on distribution of capital investment costs to erect a WPT for five European countries [81] have been generalized. Depending on countries from 60 up to 82% of capital investments are a share alone WPT. The costs of the foundation (5–12%) and costs of electrical connections (4–8%) are the most significant items of expenses. It is necessary to perceive electrical connection costs, mainly, on step-up transformers and between WPT. The manufacturers deliver WPT with voltage output of 690 V. Depending on the site of concrete object, transportation cost and the expenses on infrastructure and just as on hooking up to a power system can compound considerable proportion of investments. In most of European countries, where there is a dense network of communications spacing interval from the suppliers up to customers is very close, the above-stated items of costs make a minor part. On the contrary, in countries like: Spain, Greece, and Turkey which are not developed enough in power networks, it is necessary to allow these costs more carefully.

As is known, the output of WPT is proportional to the cube of wind speed, and consequently, the cost price of the developed electric power depends essentially on the average yearly speed in the given locality. Therefore, for example, the average wind speed

Table 10
Breakdown of windfarm investment costs, % [81]

Item	Germany	Spain	The Netherlands	Denmark	Finland
Foundation	6–9	5	6	6	10–12
Electrical connection	5–6	10	9	4	6–8
Land purchase	2–3			1	
Planning costs	1–2	1		1	
Approvals	3–4	1			
Infrastructure	1–3	1	1	1	
Wind Turbines	60–75	75	82	79	75–78
Management		1			
Grid Connection	5–8	4	1	7	
Miscellaneous	1–2	2	1	1	4–6

in Denmark measured at the standard altitude of 10 m oscillates from 4.9 to 5.6 m/s, which is equivalent of the representative speed of 6.5 m/s at the altitude of the turbine axes of 50 m [82]. The average cost of the electric energy produced on WPT by the power companies [82] is 0.04 $/kWh. This value is obtained for the 20 years WPT service life and 5–6% of the profit. The in-depth research [83] of electricity produced by WPT for conditions prevailing in Germany was conducted. For 10 years, this value has decreased more than twice and has compounded in 1999, 13.3 pfennig for one kW h. This index is counted from 20 years service life, mean yearly wind speed of 5.5 m/s at the altitude 30 m, 7.5% profit, 2% yearly expenses for repair and maintenance of a WPT and 3.2% operating cost. It is of no doubt that at higher mean yearly wind speeds, the cost of the electric power is reduced sharply.

Above, we have considered all basic aspects of development of wind power engineering in the world. A number of problems have remained without consideration because of limitation of a volume of the article. It is of no doubt, that the wind power has left a stage of pioneering development and has entered an era of industrial development. Germany, Spain, USA, Denmark and India enter the group of leading countries. Many countries have elaborated and accepted to implement the national development programs of wind power. In the next 20 years, the specific weight of wind power engineering can exceed a share of hydropower. In the light of above, it is interesting to consider the wind potentials in Turkey.

5. Wind energy potentials in Turkey

Although the first Turkish wind turbine was constructed in Çeşme at the Golden Dolphin Hotel by Vestas in 1985 (55 kW), the development of modern Turkish wind power engineering began from 21st of November 1998 when the first 3 Enercon E-40 wind turbines of 500 kW each began to operate at Alacati, Izmir. Then, the windfarm consisting of 12 Vestas V44/600 turbines was constructed at the same locality in November 1998 and the third wind farm with total installed capacity of 10.2 MW started to operate from June 2000 at Bozcaada Island. However, these capacities of constructed WPT do not reflect the real potential of Turkey.

Above, we pointed out that there are many publications of Turkish researchers relating wind energy potentials in separate regions of Turkey. Results of these investigations can be found in [22–43]. The overwhelming part of these investigations is based on the data of meteorology stations of Turkey. As a result of long-time work, in June 2002, Turkey's Wind Atlas [40] was assembled and published by the Turkish State Meteorology Organization (SMO) and General Directorate of Electrical Power Resources Survey and Development Administration of Turkey (EIE). Results of observations on 45 meteorology stations of Turkey are summarized briefly in Table 11. As seen from this table, it is impossible to draw conclusion on wind energy potentials in many regions of Turkey. Nevertheless, many researchers used data from meteorology stations to assess potentials in various regions of Turkey [22–33,35,37,38,44]. The majority of meteorology stations of Turkey were established more than 50 years ago. As a result of urbanization, many meteorology stations found themselves in city boundaries. Naturally, when these

Table 11
Wind characteristics registered at some SMO stations in Turkey [40]

No.	Station name	Latitude, N (degree)	Longitude, E (degree)	Altitude (m)	Anemometer height (m)	Observation period	Average wind speed (m/s)
1	Afyon	38°44′23″	30°33′38″	1034	12	1989–98	1.8
2	Ağrı	37°43′52″	43°03′20″	1632	10	1989–98	1.7
3	Akçabat	41°01′59″	39°33′38″	3	13	1989–98	1.9
4	Akçakoca	41°05′29″	31°08′00″	10	10	1989–98	1.8
5	Amasra	41°45′02″	32°23′03″	73	10	1989–98	5.2
6	Ardahan	41°06′26″	42°42′21″	1829	10	1989–98	1.9
7	**Bandırma**	**40°19′54″**	**27°59′56**	**58**	**11**	**1989–98**	**4.0**
8	**Bergama**	**39°07′30″**	**27°11′15″**	**53**	**12.5**	**1989–98**	**3.0**
9	Bozcaada	39°50′00″	26°04′25″	28	10	1989–98	5.8
10	Bursa	40°13′54″	29°00′49″	100	11	1990–98	1.8
11	Cihanbeyli	38°39′03″	32°55′23″	969	10	1989–98	2.9
12	Çanakkale	40°08′33″	26°24′00″	6	10	1989–98	3.7
13	Çorum	40°32′51″	34°56′11″	776	10	1989–98	1.8
14	Dalaman	36°46′26″	28°47′58″	13	13	1989–98	2.6
15	Diyarbakır	37°54′21″	40°12′08″	677	15	1989–98	2.8
16	Elaziğ	38°38′43″	39°15′24″	990	10	1989–98	2.7
17	Erzincan	39°45′07″	39°29′12″	1218	10	1989–98	1.7
18	Erzurum	39°57′05″	41°10′21″	1758	10	1989–98	2.8
19	Etimesgut	39°57′23″	32°41′11″	800	20	1989–98	2.2
20	Gönen	40°06′53″	27°38′35″	37	10	1989–98	2.4
21	Güney	38°09′07″	29°03′34″	805	10	1989–98	4.3
22	Iğdır	39°55′39″	44°03′14″	858	11	1990–98	1.0
23	İpsala	40°55′06	26°22′51″	10	14	1989–98	2.9
24	Kangal	39°14′37″	37°23′20″	1512	10	1989–98	2.6
25	Karapınar	37°42′56″	33°31′38″	1004	10	1989–98	2.3
26	Karataş	36°34′11″	35°23′29″	22	10	1989–98	3.1
27	Kayseri	38°41′28″	35°29′58″	1093	10	1989–98	1.8
28	Kozan	37°26′04″	35°49′16″	109	10	1992–98	2.1
29	Kuşadası	37°51′40″	27°15′56″	22	14	1989–98	2.2
30	Malatya	38°20′14″	38°13′03″	948	13	1991–98	1.9
31	Mardin	37°18′50″	40°43′37″	1050	10	1989–98	3.9
32	Muş	38°45′02″	41°30′09″	1320	10	1989–98	1.1
33	Ordu	40°59′06″	37°53′12″	4	12.7	1989–98	1.5
34	Pazar	41°10′43″	40°53′57″	79	10	1989–98	2.0
35	Pınarbaşı	38°43′33″	36°23′30″	1500	10	1989–98	3.9
36	Polatlı	39°35′06″	32°09′37″	885	10	1989–98	2.5
37	Samsun	41°20′42″	36°15′18″	4	13	1989–98	2.4
38	Seydişehir	37°25′40″	31°50′56″	1131	10	1989–98	1.9
39	Siirt	37°55′58″	41°56′10″	896	10	1989–98	1.3
40	Silifke	36°22′58″	33°56′19″	15	10	1989–98	2.1
41	Sinop	42°01′51″	35°09′18″	32	10	1989–98	**2.9**
42	Siverek	37°45′20″	39°20′00″	801	14	1989–98	2.9
43	Suşehri	40°09′47″	38°04′26″	1163	10	1989–98	3.2
44	Şile	41°10′13″	29°36′05″	31	10	1989–98	3.4
45	Van	38°28′14″	43°20′42″	1661	10	1991–98	2.5

meteorology stations were established, the places with high wind speed were not considered as perspective renewable sources of energy.

Understanding wind energy as one of the perspective renewable sources of energy for Turkey stimulated establishing new wind speed registration stations in the most perspective regions of Turkey as well as more detail investigations in separate regions by S. Tolun et al. [25] and F. Türksoy [37], C. Dündar and D. Inan [28–30], M. Durak and Z. Shen [39], V. Karslı and C. Geçit [42], B. Ozerdem and M. Turkeli [43]. In Tables 12–13, characteristics of wind stations as well as registered by Directorate of Electrical Power Resources Survey and Development Administration wind speed [84] in the most promising regions of Turkey are presented.

Comparison of wind speed data registered by EIE and SMO (see Tables 11 and 13, bold letters) for Bandırma, Bergama and Sinop shows that EIE stations indicated higher values than SMO stations (1.2–3.0 m/s for Bandırma, 3.2 m/s for Bergama and 1.3 m/s for Sinop). Such a discrepancy is also observed for the Bodrum region. According to Z. Şen et al. [32], the average wind speed registered at the meteorology station in Bodrum city is 3.7 m/s. At same time, the wind speed registered by EIE at Yalıkavak (distance from Bodrum is about 25 km), as seen from Table 13, is 6.1 m/s. In such a way, the creation of national network of wind speed stations by EIE legitimated expectations.

The wind energy potential of Turkey was a subject of investigation for many researchers [22–24,33,35,36,39,41]. None of these researchers gave a quantitative estimation of wind energy potential of Turkey in whole. Studying the wind energy potentials of European OECD countries (see Table 14) Van Wijk and Coelingh [46] found that Turkey has the highest technical potential—83,000 MW. At the same time, Ergün

Table 12
EIE wind stations characteristics (anemometer height-10 m)

	Station name	Observation period
1	Akhisar (Manısa)	1993–2003
2	Bababurnu (Zonguldak?)	1998–2003
3	Bandırma-1 (Balıkesir)	1991–1996
4	Bandırma-2 (Balıkesir)	2002–2003
5	Belen (Hatay)	1994–2003
6	Bergama (Izmir)	2001–2003
7	Datça (Muğla)	1994–2003
8	Didim 10 m (Aydın)	1993–2000
9	Didim 30 m (Aydın)	2000–2003
10	Foca (Izmir)	1997–2003
11	Gelendost (Isparta)	1997–2003
12	Gelibolu (Çanakkale)	1998–2003
13	Gökçeada (Çanakkale?)	1994–2003
14	Karabiga (Çanakkale)	1992–1996
15	Kocadağ (Çeşme)	1994–2002
16	Nurdağı (Gaziantep)	1991–1996
17	Şenköy (Hatay)	1992–1994
18	Sinop	1996–2002
19	Soke (Aydın)	1996–2003
20	Yalıkavak (Bodrum, Muğla)	1996–2003

Table 13
Wind speed registered at EIE stations [84]

No.	Location	Average monthly wind speed, m/s												Average annual
		1	2	3	4	5	6	7	8	9	10	11	12	
1	Akhisar (Manısa)	5.5	6.3	6.4	5.0	5.5	7.1	8.6	8.4	5.7	5.7	4.9	6.0	6.2
2	Bababurnu (Zonguldak)	5.6	6.0	5.9	5.1	4.3	5.5	5.8	6.1	4.6	4.9	5.2	6.6	5.5
3	**Bandırma-1 alıkesir)**	**5.3**	**5.7**	**6.0**	**5.0**	**3.8**	**4.7**	**6.1**	**5.7**	**4.8**	**5.6**	**4.3**	**5.1**	**5.2**
4	**Bandırma-2 (Balıkesir)**	**6.9**	**7.8**	**7.9**	**6.3**	**6.7**	**6.5**	**6.7**	**7.9**	**6.1**	**8.4**	**8.1**	**9.5**	**7.0**
5	Belen (Hatay)	5.6	5.6	5.7	5.7	6.4	8.7	10.8	10.4	7.7	4.9	4.8	5.1	6.7
6	**Bergama (Izmir)**	**5.1**	**7.4**	**6.3**	**5.2**	**5.3**	**6.3**	**6.8**	**7.8**	**4.8**	**8.4**	**5.6**	**7.7**	**6.2**
7	Datça (Muğla)	5.0	5.7	5.8	5.4	3.1	6.4	6.2	7.1	6.0	5.2	4.5	5.3	5.6
8	Didim 10m (Aydın)	5.1	5.3	5.4	4.6	3.9	4.6	4.9	4.6	4.0	3.9	5.0	5.3	4.7
9	Didim 30m (Aydın)	4.6	4.1	4.3	4.1	3.0	4.2	4.4	4.0	3.4	4.0	3.8	5.1	4.1
10	Foca (Izmir)	5.2	5.6	5.4	4.5	4.7	5.6	5.5	6.0	5.0	5.1	4.7	6.3	5.3
11	Gelendost (Isparta)	4.7	5.7	5.4	5.7	4.5	4.7	4.8	4.6	4.2	4.3	4.0	5.3	4.9
12	Gelibolu (Çanakkale)	7.1	7.0	6.9	5.2	5.6	5.8	6.1	7.5	6.2	6.3	6.9	8.0	6.6
13	Gökçeada (Çanakkale)	7.5	7.5	7.6	6.2	5.4	5.5	6.8	7.0	5.6	6.9	6.7	8.4	6.8
14	Karabiga (Çanakkale)	7.5	6.7	7.0	5.1	5.4	5.2	6.8	7.1	6.4	7.4	7.3	6.9	6.5
15	Kocadağ (Çeşme)	8.8	9.2	9.1	7.2	6.2	6.8	8.9	8.7	7.2	7.8	8.4	9.9	8.6
16	Nurdağı (Gaziantep)	4.1	4.7	5.2	6.2	6.7	9.7	13.4	12.0	8.9	4.7	3.5	3.7	6.9
17	Şenköy (Hatay)	7.1	7.5	8.9	8.0	6.7	8.1	9.8	7.9	6.9	6.2	7.6	6.5	7.7
18	**Sinop**	**4.3**	**4.5**	**4.7**	**4.9**	**5.0**	**5.4**	**4.5**	**4.1**	**4.2**	**4.4**	**4.6**	**4.4**	**4.4**
19	Soke (Aydın)	3.7	3.7	3.7	3.3	4.0	5.4	5.3	5.3	3.9	3.8	3.2	3.4	4.1
20	Yalıkavak (Bodrum)	5.8	6.9	6.9	6.4	5.6	6.4	6.2	6.3	5.8	5.4	5.1	6.7	6.1

Table 14
European OECD countries wind potential [46]

European OECD countries	Territory (thousand km^2)	Specific wind potential (class >3) (thousand km^2)	Side potential (km^2)	Technical potential	
				MW	TWh/yr
Turkey	781	418	9960	83000	166
UK	244	171	6840	57000	114
Spain	505	200	5120	43000	86
France	547	216	5080	42000	85
Norway	324	217	4560	38000	76
Italy	301	194	4160	35000	69
Greece	132	73	2640	22000	44
Ireland	70	67	2680	22000	44
Sweden	450	119	2440	20000	41
Iceland	103	103	2080	17000	34
Denmark	43	43	1720	14000	29
Germany	357	39	1400	**12000**	24
Portugal	92	31	880	7000	15
Finland	337	17	440	4000	7
The Netherlands	41	10	400	3000	7
Austria	84	40	200	2000	3
Belgium	31	7	280	2000	5
Switzerland	41	21	80	1000	1
Luxemburg	3	0	0	0	0

Özakat [85] estimated the technical potential of wind energy in Turkey as 116,000 MW. Unfortunately, at present time, we do not have enough wind speed data registered at wind speed stations along all perspective sites of Turkey. Nevertheless, these values can be considered as minimal technical potentials since assessment of Van Wijk and Coelingh was based on SMO data. These data as has been shown above are less than the data observed at EIE wind speed stations. The technical potential of Germany was estimated in [46], as 12,000 MW. As of 30 June 2003 [86], the installed capacity of wind turbines in

Table 15
Electric power capacity development in Turkey, MW [82]

Years	Thermal	Hydro + renewables			
		Total	Wind		
			[41,84]	[87]	[3,85,86]*
2000**	15560	10540	19	400	19
2005	25654	14242	1359	5000	1840
2010	40954	19536	2979	10000	4565
2015	55904	25262	5142		7230
2020	76304	28589	7849	20000	10620
2025			9733		13160
2030			11200		15885

*Calculation of authors assuming wind turbine utilization factor is 0.18 and 1ktoe is 86 GWh. **Statistical data.

Germany was already 12,828 MW and by 2010 Germany plans to install 25,000 MW. Consequently, we could consider that the values presented in Table 14 is the lowest.

Above, we saw that Turkey has sufficient wind energy potentials. However, the practical utilization of wind energy as known is limited by installed capacity of 19 MW. At present, there is a preliminary outline of Turkish electric power capacity up to 2020 (see Table 15). According to the draft [87], thermal power keeps its dominant role in 2000 and 2020. The demand for electricity generated from thermal power is estimated to reach 72% in 2020, from 59% in 2000. Hydro and renewable powers are estimated to decline in total demand. This share is expected to decline to 27% from the current level of 41%. In this table, the available scenarios of wind power development are also presented. At a first glace, all presented scenarios are very optimistic, particularly the one submitted by Group on Research of New and Renewable Energy Resources and Technology (Kocaeli University) [88]. Nevertheless, this scenario is highly probable because of the unprecedented rate of wind power development in Germany and Spain. Even such an authorized company as BTM Consult did not forecast similar rate in those countries. Consequently, for penetration of a new technology such as wind power engineering in power industry, it is important to create all favorable conditions as they were made in Germany and Spain. These scenarios of wind power development in the nearest 20–25 years shows that, at favorable conditions, it is possible to keep the share of hydro and renewable power capacity in the level of 35–40% (in 2020).

As show in earlier publications [36,41,89–92], many Turkish companies are interested in developing wind power industry. To meet with the requirement of International Investment Institutions, all wind farm projects must be furnished by wind speed data registered under control of well known international scientific organization. Therefore, according to Klug et al. [36], German Wind Energy Institute (DEWI) measured the wind speed at 43 sites in Turkey to provide the orders to companies like: Aksa Üretim A.S., Best A.S., Bim Ltd Sti., InnoVent, Project GmbH, Taboğlu, Türk DeWind, and Yelen Energy A.S. For instance, Interwind, the Swiss Engineering and Consulting Company [91] carried out similar measurements at 22 locations in 2000 for companies like: Bayindir Enerji A.S., Wind Generation Ltd, and Zorlu Enerji A.S. At present, observations on wind speed that met with the requirements of wind power industry are being carrying out at about 300 locations in Turkey [93]. Earlier Interwind Company fulfilled wind speed measurements for other Turkish companies. Besides of this, Interwind prepared several feasibility studies based on the orders of some Turkish companies. By the end of 1999, 39 projects relating to construction of wind farms at the most promising locations of Turkey were submitted to Ministry of Energy and Natural Resources. Table 16 summarizes all these projects. The total power capacity of projects is about 1056–1184 MW. As known, three of them were constructed and at present successfully operated. Until now, the rest projects wait for the solution.

The commercial companies show the greatest interest in Izmir province. The total capacity of 15 wind farm projects submitted for construction in that province is about 500 MW. It is also offered to construct 7 projects in Çanakkale province with total capacity 121–156 MW, 4 projects in Balıkesir province with 127 MW, 3 projects in Hatay province with 142 MW. Other provinces are less attractive at present than those

Table 16
Wind power plant projects in Turkey [41,88]

	Project name	Company developed the project	Location	Project power, MW
Built wind power plants				
1	Germiyan R.S.	Delta Plastik	Çeşme-Germıyan	1.5
2	Çeşme Alaçatı R.S.	Ares A.Ş.	Izmir-Çeşme-Alaçatı	7.2
3	Bozcaada R.S.	Demirer Holding A.Ş.	Çanakkale	10.2
Wind projects waiting decision of State Planning Organization				
4	Kacadağ R.S.	AS Makinsan	Çanakkale	50.4
5	Çanakkale R.S.	AS Makinsan	Çanakkale	30
Wind projects under contract discussion				
6	Mazıdağı R.S.	Demirer Holding A.Ş.	Izmir-Çeşme-Alaçatı	39
Wind projects whose feasibility reports are being assessed				
7	Akhisar R.S.	Ak-En (Sasaş İnşaat)	Manisa-Akhisar	12
8	Akhisar R.S.	Demirer Holding A.Ş.	Manisa-Akhisar	30
9	Bandırma R.S.	Atlantis Ticaret	Balıkesir-Bandırma	15
10	Beyoba R.S.	Atlantis Ticaret	Manisa-Akhisar-Beyoba	7.92
11	Çeşme R.S.	Prokon	Izmir-Çeşme	12
12	Datça R.S.	Demirer Holding A.Ş.	Muğla-Datça	28.8
13	Datça R.S.	Atlantis Ticaret	Muğla-Datça	12.54
14	Intepe R.S.	Interwind	Çanakkale-Intepe	12
15	Intepe R.S.	Interwınd	Çanakkale-Intepe	30
16	Karaburun R.S.	Atlantis Ticaret	Izmır-Karaburun	22.5
17	Yalıkavak R.S.	Atlantis Ticaret	Muğla-Bodrum-Yalıkavak	7.92
Wind projects that awaits revision feasibility reports				
18	Gökçeada R.S.	Simelko	Çanakkale-Gökçeada	5
Wind projects that await feasibility				
19	Belen R.S.	Teknik Ticaret	Hatay-Belen	20–30
20	Çeres R.S.	Interwınd	Izmir-Çeşme	18–25.5
21	Ekinli R.S.	Deryalar Ltd	Bandırma-Karacabey	39.6
22	Güzelyer R.S.	Enda Energji Üretim A.Ş.	Izmir-Çeşme	50.4
23	Hacıömerli R.S.	Demirer Holding A.Ş.	Izmir-Hacıömerli	45
24	Kapıdağ R.S.	AS Makinsan	Balıkesir-Erdek	20–35
25	Karabiga R.S.	AS Makinsan	Çanakkale-Karabiga	15–50
26	Kocaali R.S.	Derin Ltd	Tekirdağ-Şarköy	31.2
27	Kocadağ R.S.	Mage A.Ş.	Izmir-Çeşme-Kocadağ	26.25
28	Kumkale R.S.	Demirer Holding A.Ş.	Izmir-Çeşme	12.6
29	Lapseki R.S.	Atlantis Ticaret	Çanakkale-Lapseki	15
30	Mazıdağı-2 R.S.	Demirer Holding A.Ş.	Izmir-Çeşme	90
31	Mazıdağı-3 R.S.	Yapisan Ltd	Izmir-Çeşme	39.6
32	Paşalimanı R.S.	AS Makinsan	Marmara-Kapıdağ	9
33	Şenköy R.S.	Akfirat A.Ş.	Hatay-Şenköy	12
34	Seyitali R.S.	Derin Ltd	Izmir-Aliağa	51
35	Taştepe R.S.	Fora A.Ş.	Bandırma-Taştepe	37.8
36	TopdağR.S.	Derin Ltd	Sinop	33
37	Yaylaköy R.S.	Mage A.Ş.	Izmir-Karaburun	15
38	Yellıce Belen R.S.	AS Makinsan	Hatay-Belen-Yellice	70–100
39	Yenişarkan R.S.	Yapısan Inşaat Ltd	Izmir-Aliağa-Bahçedere	54
40	Zeytinbağ R.S.	Deryalar Ltd	Bursa-Zeytinbağ	30–60

mentioned. Makinsan proposed six projects with total capacity 194–274 MW, Demirer Holding—six projects with 256 MW, and Atlantis Ticaret—six projects with 81 MW. The largest projects are: Yellice Belen R.S. (AS Makinsan)—70–100 MW, Mazidağ 2 (Demirer Holding)—90 MW, Yenişarkan R.S. (Yapisan Inşaat Ltd)—54 MW, Kocadağ R.S. (AS Makinsan)—50.4 MW, and Güzelyer R.S. (Enda Enerji Üretim)—50.4 MW.

6. Conclusions

The world wind power engineering entered during the stage of industrial development. By the end of 2002, the accumulated installed capacity of wind turbines reached 32037 MW. Vestas AS (Denmark), Enercon (Germany), and NEG Micon (Denmark) produce more than 1000 MW wind turbines each, annually. During the last 5 years, Germany and Spain achieved striking success in installing 9 GW and 4.5 GW wind power. This success was reached because of accelerated development of wind turbines production industry in Germany and Spain. The recent years are characterized by construction of large wind power farms with capacity 50–250 MW in mainly USA and Spain. Construction of large off-shore wind farms has begun. During the last 3 years, Denmark introduced into operation the largest three offshore projects: Horn Rev Wind farm (160 MW), Nysted Offshore Wind farm (158.4 MW), and Middelgrunden Offshore Wind Farm (40 MW). The main manufacturers begin to produce wind turbines with a capacity 2 and 2.5 MW. In the near future, serial production of wind turbines with capacity 3–5 MW is expected. To decrease the investment cost, the production of wind turbines is coming near to the places of their installation. In the present day, investment cost of wind turbines is between 925 and 1200 US$/kW which is compatible with one for thermal power plants working on coal.

Taking into account the giant perspectives of utilization of wind energy, Turkish scientists carried out during last 10 years many investigations in various promising territories of Turkey. As a result of efforts of the General Directorate of Electrical Power Resources Survey and Development Administration and State Meteorology Organization, Wind Atlas of Turkey was published. Wind speed data registered at EIE stations show that Turkey has sufficient wind energy potential, which exceeds the potential of hydropower which is estimated to be 35,539 MW [95–97]. The large number of applications from Turkish companies to construct of wind power plants is the evidence for prospective of wind power industry in Turkey.

Nevertheless, as seen below, there are many barriers and obstacles that hamper the progress of wind power technology diffusion into power industry of Turkey. Some of these barriers have general character that stay before power industry as a whole. Others possess narrow character typical only for wind power. Among formers, H. Akbulut [98–99] pointed out follows: the necessity for regulatory reforms in energy sector; creation of High National Energy Council; the active participation of the relevant factors in the energy-making process; the integration of the Turkish energy sector in international market and privatization; the state bodies should cooperate

closely with scientific organizations, private sector, public associations, political parties, and interest groups in the process of planning; necessity of developing various contemporary scientific models for energy planning. To the latter barriers, Hanağasıoğlu [33] takes following obstacles: definition of the specific place of renewable energy sources in the overall energy politics of Turkey; reinforcement of infrastructure of electrical networks at high wind locations as a matter of priority; revision of legal frame work for independent power producers to address the realities of the present and demands of the future. Karaata and Ekmekci [94] presented some measures of general and specific character for developing wind power. Other concrete measures to promotion wind energy projects can be found in [100–102].

Summarizing all the above-mentioned aspects, one can say that to promote wind power technology diffusion in Turkey on a large scale, the following steps should be taken in the nearest future:

- To develop and pass the Law on renewable energy sources. This law must have the content: the procedure for considering renewable energy projects; tax and regulation issues; the incentives and mechanisms; tariffs on electricity generated by wind turbines and other renewables on nearest 10 years; the coordination of activity of state, research and private sector bodies and organizations, the creation of National fund for financing scientific research, wind speed observation stations all over the perspective regions of Turkey, and creation of New Wind Atlas of Turkey based on wind speed measurements meeting all international requirements; etc.
- Not only State bodies, but all interested groups namely the scientific community, business circles, and civil associations must participate equally in decision-making and planning processes.
- To elaborate the National program on development of renewable power engineering (with wind power section) for the next 20 years. This program must take into account all positive experience accumulated by countries like Germany and Spain. It should correct this program every 2 years considering the real rates of growth taking into account the world achievements in renewables power technologies.
- To reconsider in short time the applications of Turkish and foreign companies on the construction of wind farms. In consideration, the experience in construction of large wind farms in USA, Spain, and Denmark should be taken into account.
- To begin the creation of high-powered electricity networks in most windy regions of Turkey, the requirements of dynamic development of wind power industry in coming 20–30 years.
- To create the favorable conditions for organizations wind power manufacturing factories. It allows to create new work places on one hand and reduce transportation expenses on the other hand.
- The state bodies, research organizations, and civil professional associations responsible for the development of renewable sources of energy must strength the work on dissemination of world wind power industry achievements among police-makers (in first term), corresponding ministries and agencies, local authorities as well as among population.

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